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Dear Susan,

This letter is the fourth quarterly progress report for grant N00014-92-J-1945, entitled "Long Term Learning: Integration of knowledge acquisition and knowledge compilation." It covers the period April 1, 1993 to June 30, 1993.

Two goals were achieved during this quarter. First, we re-examined one of the oldest expert-novice findings in the literature: when solving physics problems, novices do write equations in backwards order, starting at the sought quantity and working towards the given quantities. Experts write equations in forwards order. This was first noted by Simon and Simon, and replicated in studies by Larkin and Sweller. However, it is an odd finding in that similar strategy shifts that could occur in other skills (e.g., geometry theorem proving and programming) were not observed to occur. In those skills, both experts and novices tended to use a variety of strategies, but the proportions did not vary with levels of expertise. We began by asking what made physics different that practice should cause a strategy shift.

We began by seeing what it would take to make Cascade shift from backwards to forwards equation-writing. We designed several methods, but none seems more obviously correct than the others. Moreover, we discovered several different ways to do backwards chaining, and we were not sure which one was used by novices. We re-read Larkin's paper's, which used the most sophisticated kind of physics, but the papers did not distinguish among the various types of backwards chaining. Fortunately, we had earlier obtained Larkin's protocols for her expert-novice studies, so we began to re-analyze them in order to determine exactly what kind of strategy the novices were employing.

Much to our surprise, we discovered that the novices were not consistently employing any of the backwards chaining strategies we knew of. They would usually forward chain up to the point where they had drawn a force diagram and identified some potentially useful equations. What they did next seemed to vary with individuals and problems. Sometimes they would switch to backwards chaining and sometimes they would continue forwards chaining. Sometimes they would mix the two. If one concentrates only on the written work, then there does not appear to be much use of backwards chaining among the novices. If a subject were doing backwards chaining, then the first equation containing the problem's sought should be in position 1, or perhaps it should be in position 2 with drawing a force-diagram in position 1. Instead, the average position was 7.5. Subjects typically drew a force diagram and wrote a few force laws before writing the kinematics equations that contained the sought quantities.

About this time, I gave an invited presentation at the AISB conference in Britain, where I met Tony Priest, who has been working on and off for years on modelling physics problem solving strategies. He was unhappy with the Larkin study because it had been done with only a small number of subjects (9 novices; 11 experts) and an even smaller number of physics problems (2), and yet this sample was used to justify a general assertion applying to all novices and all problems. Priest and Lindsay (1992, British Journal of Psychology) repeated the Larkin study with more subjects (79) and more problems (6). They found no evidence of an expert-novice shift. At all levels of expertise, subjects used forwards chaining about 80% of the time. On a hunch, we examined all the mechanics examples of the Halliday and Resnick textbook, and they also solved problems in forwards order about 80% of the time. It appears that the original Larkin findings were a sampling artifact, and that there is no expert-novice difference in the direction in which the write equations.

However, there is a strategy difference between experts and novices. It was

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clear in Larkin's protocols that before the experts write their first equation, they usually have a plan for the whole solution. Sometimes they plan the solution out loud; other problems are so simple that they either know a plan or figure it out so rapidly that they do not bother to talk during the planning process. Priest and Lindsay (1992) found that experts could produce a plan for the solution whereas novices could not (as did Chi, Feltovitch and Glaser, 1981, which a smaller sample).

These findings, as well as several others in the expert-novice literature, led us to the conclusion that the chief difference in the problem solving strategies of experts and novices is that experts can plan a solution in their heads and novices cannot. This casts doubt on mechanisms such as Soar's chunking and ACT's production compounding, which were designed to cause a backwards-to-forwards shift in strategy. We are currently of the opinion that no such special purpose mechanisms are needed to account for the expert's ability to plan. We believe that novices already know how to plan with equations because they learned that skill during high-school algebra. However, they cannot do such planning in physics because they are not familiar enough with the equations. That is, they might be able to tell that Newton's law could be applied to a certain body, but they would not be able to determine which quantities would be involved in the equation without first writing it down and doing the trigonometry. The expert can "just see" which quantities are involved, so she can plan out the effects of using the equation without writing it down.

We plan to model this in Cascade by having the productions that encode the skill of planning with equations require that the strengths of the beliefs encoding the equations be above a certain threshold before planning can successfully occur. This is a crude model of the real situation, wherein familiarity interacts with many other factors to determine working memory load and thus the capability of planning. Modelling the real situation would require a finer-grained model of memory than Cascade has. Our proposed model will produce the observed expert-novice shift and allow us to study its interaction with other forms of learning.

The second achievement of this quarter was isolation of some expert knowledge for system definition. When we modelled the solving of some harder physics problems, we noted that it is sometimes not obvious how to choose the set of bodies that the laws would apply to (the system). Experts seem to do better at this than novices. We defined and tested some heuristics for this subskill, but we are not yet sure how the expert acquires them.

Best regards,

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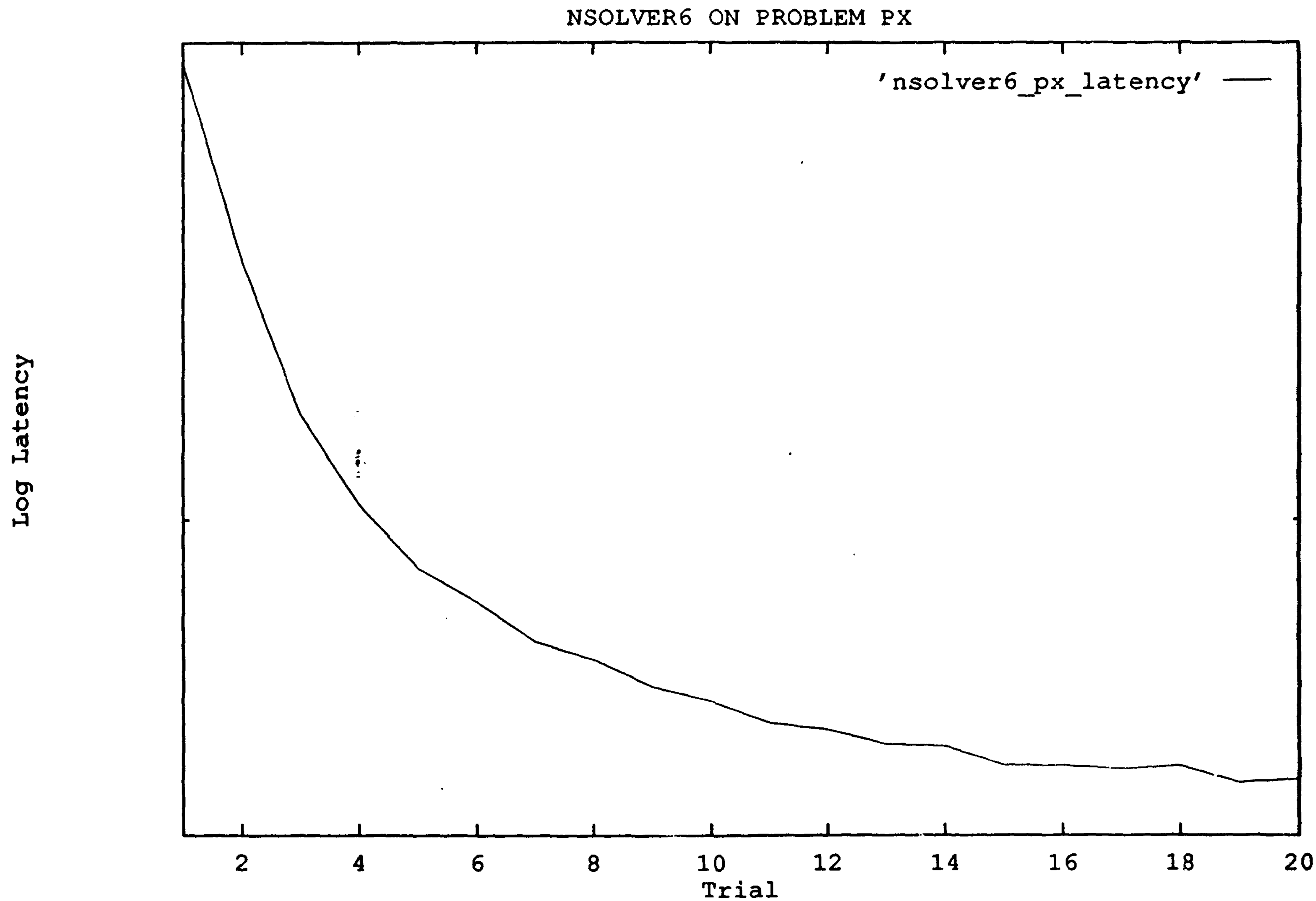
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NSOLVER6 ON PROBLEM PX

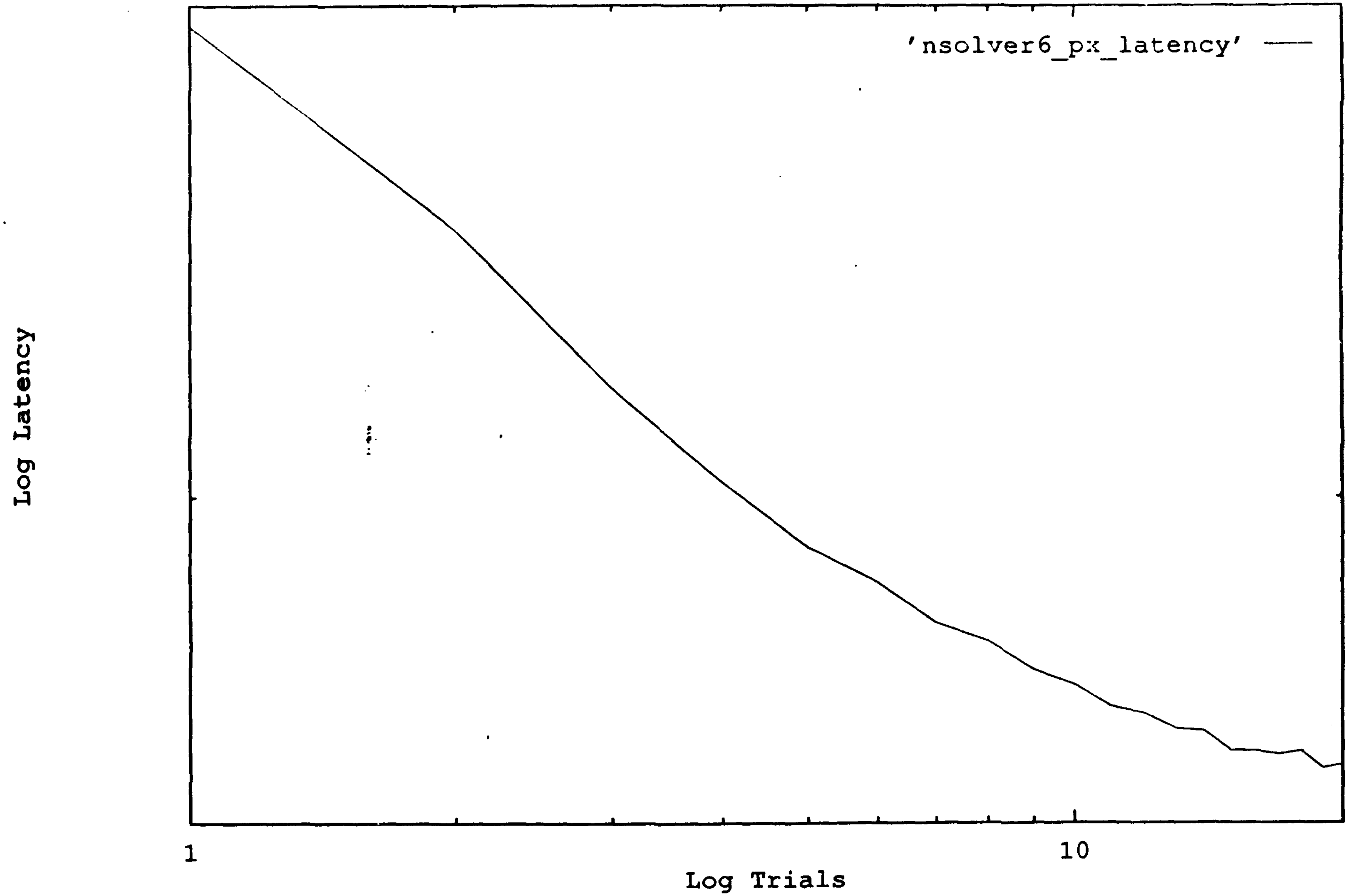

Figure 2